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Parametric Analysis of the Electric Utility Market for Advanced Load-Leveling Batteries

Final Report

February 1979

Prepared for:
U.S. Department of Energy
Assistant Secretary for Energy Technology
Division of Electric Energy Systems

Under Contract No. EC-77-C-01-5036

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PARAMETRIC ANALYSIS OF THE ELECTRIC
UTILITY MARKET FOR ADVANCED LOAD-LEVELING BATTERIES

1.0 Task Definition

The purpose of this task is to examine the market for batteries in utility load-leveling service as a function of the Battery System Cost characteristics in order to give the Department of Energy a method of assessing the results of various program alternatives. The sensitivity of the "benefits" (barrels of oil saved) which might be derived to the timing of the market (i.e. when it begins) is also investigated. (The real cost of fuel is to be assumed to increase 2.4% per year.)

2.0 General Background

Few new products enter the market by totally displacing the old products the first year in which they are introduced. The more usual case is that the new product displaces the old product very slowly at first. The old product may gradually disappear from the market with time, or if the products are comparable, the two products will share the market indefinitely.

Figure 1 illustrates the general nature of this product displacement. The ordinate is the percentage of the total market captured by the new product. The abscissa is some measure of the relative effectiveness of the competing products. If the new product is clearly superior to the old, it will eventually capture the total market; the time required for the new product to dominate the market would be the time needed to educate potential buyers. The relative effectiveness and the associated displacement time of Battery Storage Systems and gas turbines is dominated by how fast the real cost of fuel is likely to increase. At present, the total costs (capital and operating costs) of battery systems are significantly higher than the total costs of gas turbines; i.e. the battery systems are clearly more costly. If the cost of fuel increases at a rate higher than inflation, the battery systems with their low fuel costs will begin to compete; eventually the batteries will become clearly superior to gas turbines and will dominate the market. For some period of time, the batteries will be able to compete with gas turbines in only a portion of the market.

RELATIVE EFFECTIVENESS (MAY CHANGE WITH TIME)

FIGURE 1

MARKET PENETRATION OF NEW PRODUCT
AS A FUNCTION OF THE RELATIVE EFFECTIVENESS
OF THE NEW PRODUCT COMPARED WITH THE OLD

The concept illustrated in Figure 1 applies to all new technologies. However, using this general function to estimate how the market for battery systems might develop requires answers to the following questions:

- How large is the total market for this new technology?
- How is the "relative effectiveness" of Battery Storage Systems related to the cost of fuel, the capital cost of the battery and the perception of the "credits" associated with battery systems and how do these vary with time?

Most of the answers to these questions were obtained by studying the data developed by MITRE/METREK for a market assessment of battery systems using Lead/Acid Batteries⁽¹⁾. MITRE's market analysis considered a large variety of variables; since the resources and time available for the present task were limited, it was not possible to either duplicate or confirm their work in detail. Thus, the initial results of this study depend upon the assumptions used by MITRE. However, where these assumptions were incomplete, the results were adjusted (see page 15). The supplementary information was obtained from studies performed by Arthur D. Little, Inc.⁽²⁾ and by PSE&G^(3,4).

3.0 Maximum Market Size

Battery Storage Systems can be used to meet the peak demand for power instead of gas turbines. MITRE projects that the market for peaking capacity will equal 4,050 MW/yr in the year 1985 and will increase at the rate of 4% per year until the year 1995. (We have assumed that this market will increase at this rate between 1985 and 2015.) We estimate that battery systems with a 5 hour storage capacity can eventually meet half of this market (i.e. they can meet the load otherwise met by 50% of the gas turbines).

Battery Storage Systems are not technically capable of meeting the utilities' total requirements for peaking capacity (defined to operate 1300 hours per year or less). A limited storage reservoir capacity makes the battery unsuitable for use by those utilities whose peak demand period is lengthy and relatively constant because the high capital cost of very large storage reservoirs prevents the cost-effective use of Battery Storage Systems in these utilities. PSE&G⁽³⁾ has estimated that those utilities which have a daily peak load duration of from 0 to 6 hours (durations which can be met with battery systems with 5 hours storage capacity) must meet this peak for 600 hours per year; this is roughly half the 1,300 hours per year per generator operation which is used to define peaking duty. Thus, a reasonable estimate of the maximum market size for Battery Storage Systems with a 5-hour storage capacity would be one half the total market for all peaking capacity. This maximum market size would increase 4% per year; i.e., at the same growth rate as the total market for peaking capacity.

Since the economics of Battery Storage Systems and gas turbines are assembled to depend critically on the existence of the "Spinning Reserve Credit"⁽¹⁾, the market for Battery Storage Systems cannot be larger than that required to provide the spinning reserve. MITRE, in assessing the availability of spinning reserve credits, has listed the largest generator located in each of the reliability regions. The combined capacity of all of these plants is one estimate of the amount of spinning reserve capacity required. However, this appears to underestimate the total market by a factor of two.

It is not sufficient to just compensate for the largest plant in each region. These plants are connected to the load via transmission lines, which could transmit the output of several large plants simultaneously. The unscheduled outage of a transmission line could have the same effect as the loss of a plant with several times the capacity of the largest generator. At the same time, there are usually several

large generators in a region, each located at sites far from the load centers and from each other. If the spinning reserve is far from the load that was being served by the failed generator, it will be of little help in maintaining the stability of the rest of the generators feeding that load center. Thus, the total spinning reserve in each reliability region might be twice the size of the largest generator(s). This would indicate that spinning reserve credits should be available for a total of 17.5 GWs* (1980).

MITRE indicates (Table 3-11)⁽¹⁾ that the average spinning reserve requirement is 5% of the peak load. They also indicate that the peak national power demand in 1980 will be 356 GW. Five percent of 356 is 17.8 GW.

The size of the largest plant should not be expected to remain the same as the years pass. Indeed, economies of scale will tend to force a growth in the capacities of the largest individual base load plants and transmission lines. If their capacity grows at 5% per year, the total required spinning reserve capacity will also grow 5% per year until it is roughly 20 GW in 1985.** If the sizes of the largest generators continue to grow at an average 5% per year, the total battery system capacity installed will not exceed the total required amount of spinning reserve (see Figure 6) until after the year 2015. The estimated maximum yearly market for battery systems should not be limited by the availability of a "spinning reserve credit" until after that time.

Battery Storage Systems with 10-hour storage capacity could conceivably be able to meet the requirements of the other half of the peaking market. However, because of the high capital cost of the extra storage capacity, this market would not begin to develop until well after the year 2000. At that point, it would not qualify for a "spinning reserve credit" since the need for spinning reserve would

* Twice the combined capacity of the largest generators in each region.

** The growth in the maximum plant size of the 60's and early 70's has slowed. However, it may reappear when the demand begins to grow again and when the reliability problems of large generators are solved.

have been met by 5-hour capacity systems. The absence of the spinning reserve credit will eliminate this market and thus, it can be ignored during the rest of the investigation.

A Battery Storage System having only 1 hour of storage capacity could meet a power pool's spinning reserve requirements; however, it could not provide enough energy to level the load on the pool's primary generators. Thus, the economic tradeoff would consider only the capital cost of the battery system and the "spinning reserve credit". Since both values would be less than the total costs and savings, nothing much would be gained. In addition, the barriers to the formation of a market for "generators" which cannot be used to meet the load will be severe. Thus, one would expect the market for the 1-hour capacity system to develop later than the market for the 5-hour capacity system. At that point, the need for spinning reserve will be met by the 5-hour capacity system and the market for the 1-hour capacity unit will be correspondingly small. This system can be ignored during the rest of the investigation.

In conclusion, our estimates of the maximum yearly market for 5-hour capacity Battery Storage Systems indicate that it is roughly half the total market for peaking capacity. The markets for battery systems having either 1 hour or 10 hours of storage capacity appear to be negligible.

4.0 Relative Effectiveness of Battery Systems and Gas Turbines

A variety of factors influence the relative effectiveness of Battery Storage Systems and gas turbines for the electric utilities. They are:

- An engineering/economic comparison (present worth of all future revenue requirements analyses) using all possible credits associated with the various alternatives

- The applicability and acceptability of the various credits to specific utilities, and
- Capital intensity of the various alternatives and the resulting effect on the utilities' financial objectives.

Of these factors, only the first factor has been fully considered by MITRE for estimating the size and timing of the market for Lead/Acid Battery Storage Systems. An estimate of the applicability of the credits was obtained by examining the general characteristics of the various reliability regions. How the market might be depressed by both the time required to demonstrate the reality of the various credits and the capital intensity of the battery systems was not considered. MITRE's results should be adjusted to reflect these considerations.

4.1 Engineering/Economic Comparison

A thorough engineering economic comparison of Battery Storage Systems (using Lead/Acid Batteries and gas turbines) was performed by PSE&G,⁽⁴⁾ these results were then adjusted by MITRE⁽¹⁾ to consistently reflect the economic effects of persistent inflation. The results of MITRE's modifications of PSE&G's results are shown in Table 1. This table shows that when all the various credits that can be associated with batteries are included, in the absence of any real increase in the cost of fuel with time, a battery system having a capital cost of \$445/kW will not be able to compete with gas turbines^{*}; the battery system cost would have to be about \$385/kW in order to compete. On the other hand, if the real cost of fuel were increased by roughly 1% per year^{**}, by 1995 the more expensive batteries would be able to compete and presumably, a market could develop. Thus, from an engineering/economic point of view, the critical tradeoff is between the capital cost and savings associated with

* Cases A and B both indicate a net economic penalty against Battery Storage Systems.

** This is Case C in Table 1.

TABLE 1
ECONOMIC SUMMARY

	<u>MITRE/METREK REVIEW</u>		
	<u>Case A</u>	<u>Case B</u>	<u>Case C</u>
Cost of Money	4%	10%	10%
Fuel Escalation	0%	6%	7%
Inflation Rate	0%	6%	6%
Cost (\$/kW) Battery Capital Cost	445	445	445
Savings (\$/kW) Transmission	58	55	55
Distribution	2	2	2
Production Cost and Spinning Reserve	205	214	287
Replacement Capacity	116	118	118
Net Benefit (Penalty)	(64)	(56)	17

Reference: MITRE/METREK Study

the battery system and those credits which vary with time; the spinning reserve credit was the most important of the time varying credits. MITRE used the temporal and regional dependence of the various credits and estimated how the market for lead/acid batteries would develop with time. By considering the regional dependence of the credits to some extent, MITRE did consider applicability of these credits to the average utility in the various regions. However, their market analysis did not include the delay in market penetration caused by the utilities' present reluctance to accept the magnitude of these credits or the need to address this reluctance in a commercialization plan.

4.2 Acceptability of Various Credits

The two time varying credits (reductions in the cost of operating the power pool) associated with Battery Storage Systems are:

- The production cost credit; i.e. the reduction in the cost of producing power to meet the load, and
- The spinning reserve credit; i.e. a reduction in the cost of maintaining extra capacity available to meet various contingencies.

The utilities⁽²⁾ presently believe that only a portion of these credits is achievable.

In discussing anticipated spinning reserve benefits with utility representatives, Arthur D. Little found that few would be willing to consider these benefits in deciding whether or not to purchase batteries. Even granting a successful completion of the B.E.S.T. facility and favorable feedback from a 20 MW demonstration, the view was expressed that only marginal credits would be attributed to spinning reserve cost reduction capabilities at first. There are two reasons for this view. First, a well supervised 20 MW demonstration could prove the potential of batteries to realize spinning reserve savings, but it could not prove to a specific utility that larger scale installations on an average system would realize these same benefits

under normal operating conditions. Utility engineers and managers were particularly concerned about the ability of computer systems and controls to convert the benefits of batteries to actual savings. Second, although the demonstration might go a long way in convincing utility research and development and engineering personnel, these individuals control only the first stage of the decision-making process. While systems planning personnel may be willing to include the spinning reserve credits identified in the PSE&G and MITRE studies in a first-screen revenue requirements analysis, there is no assurance that 1) financial officers would be willing to accept these credits in analyzing the effect of a battery investment on key financial indicators, or 2) corporate management would be willing to accept the risk inherent in spinning reserve projections before installations had actually realized savings under normal day-to-day operating conditions.

Thus, the perceived risk associated with this credit is probably large enough to defer the market for several years, even after the Demonstration Plant is built. If the Demonstration Plant is not built and the perceived risk thus reduced, the market for Battery Storage Systems will probably never develop. If the Demonstration Plant is built (1983), and as a result several more plants are built and also achieve spinning reserve savings, the perceived risk should be reduced and the natural (rather than experimental) market should start to develop in 1990.

Although most utilities expect fuel costs to increase somewhat faster than other costs, few are expecting them to rise as fast as the predictions of the National Energy Plan (2.3% for oil and .8% for coal) and none seems willing to take the risks associated with the assumption that oil costs will increase significantly faster than coal. The projected markets will be sensitive to the utilities' acceptance of these costs.

It may be that the utilities will not believe that the cost of fuel will increase faster than 1.5% per year until after this has been the pattern for many years. If the escalation rate is maintained at 2.4% per year but the utilities will only accept a rate of 1.5% per year, the market for Battery Storage Systems might be deferred for as long as four years. Thus, the market for Battery Storage Systems along with the markets for other energy technologies will depend on industry's acceptance of the government's intentions to reduce the usage of oil by forcing an increase in its cost.

4.3 Capital Intensity

In a previous study⁽²⁾, we asked utility officers to assess how the utilities' financial objectives and capital limitations might affect the proposed purchase of a Battery Storage System once such systems were shown to yield positive economic benefits. These individuals were reluctant to predict the effects; they noted that computer models were necessary, simply because it was virtually impossible to predict how specific projects could affect financial objectives. On the other hand, several individuals were willing to offer what might be described as a working assumption that commitments to battery projects would be postponed by 18 to 30 months on average beyond the time at which they were first shown to meet revenue requirements. If the cost of oil were to escalate at the projected rate in the interim, the delay would allow an improvement in the relative economics. This view probably represents the best assumption that can be made at this time.

5.0 Market Analysis

MITRE has assessed how the market for Lead/Acid Battery Storage Systems might develop with time:

- If the costs are generally as assumed in Table 1, and
- If the cost of fuel increases at some rate faster than inflation.

FIGURE 2
EFFECT OF OIL ESCALATION ON MARKET PENETRATION⁽¹⁾

FIGURE 3
UNADJUSTED MARKET FOR BATTERY STORAGE SYSTEMS
AS FUNCTIONS OF TIME AND CAPITAL COSTS FOR BATTERIES

* 50% of Peaking Market

FIGURE 4
 TOTAL INSTALLED BATTERY CAPACITY AND BARRELS OF OIL SAVED PER YEAR
 AS FUNCTIONS OF TIME AND BATTERY COSTS

* 1 MW of installed battery capacity saves approximately 1,600 barrels of oil per year.

If one assumes that MITRE's ⁽¹⁾ market curve (Figure 2), (cost of fuel increases 2.4% per year) is a market penetration curve (Figure 1) for a total market that increases exponentially with time, one can obtain an approximate expression for the tradeoff between the capital costs of batteries and fuel cost savings as a function of time (the relative effectiveness of battery systems) (see Appendix A). One can then extrapolate this curve to subsequent years (see Figure 3). The various terms in this expression are associated with the credits and costs of Table 1. The relative effectiveness of Battery Storage Systems having different capital costs can be obtained by adjusting these terms and the market for batteries can be calculated (see family of curves in Figure 3). If the markets develop in the manner indicated in Figure 3, the total Battery System Capacity in service as a function of time and battery costs will be shown in Figure 4. Unfortunately, these curves do not include the effect of the institutional barriers to the purchase of Battery Systems and must be corrected (see Figures 5 and 6).

The curves in Figure 3 were calculated without any consideration given to the institutional barriers to the acceptance of the various credits, as previously discussed; these curves represent the theoretically maximum market for Battery Storage Systems under the assumptions that:

- Fuel costs will increase 2.4% per year.
- The utilities accept that spinning reserve credits can be obtained on every system.
- The electric utilities have no problem raising capital.
- There is no risk associated with the purchase of Battery Storage Systems.

Since the last three assumptions are not correct, the curves in Figures 3 and 4 must be adjusted.

FIGURE 5
CORRECTED MARKET FOR BATTERY STORAGE SYSTEMS
AS FUNCTIONS OF TIME AND BATTERY COSTS

FIGURE 6
 TOTAL INSTALLED BATTERY CAPACITY AND OIL SAVINGS PER YEAR
 AS A FUNCTION OF TIME

FIGURE 7
 TOTAL AMOUNT OF OIL SAVED BETWEEN 1985 AND YEAR
 AS A FUNCTION OF TIME

If no 20 MW Demonstration Plant is built, the market will not begin to develop until it can do so without the spinning reserve credit (~ 2010). At that point, the production cost credit will be large enough to allow batteries to compete with gas turbines without the spinning reserve credit. If the demonstration plant is built, the market can begin to grow once some of the perceived risk is reduced. The market should begin to grow in 1990 and reach its economic potential roughly ten years later.

The capital intensity of Battery Storage Systems should delay the market for roughly two years; this is the result of the utilities' problems in meeting their financial objectives (see Section 4.3).

The results of these corrections to MITRE's work are shown in Figures 5 and 6. The benefits (oil saved) of a market which develops in the manner illustrated in Figure 5 is shown in Figure 7; this is the total number of barrels of oil saved between 1985 and the specific date.* Also plotted in these figures are the total installed capacity, energy saved per year, and total energy saved should Battery Storage Systems manage to capture the full 50% of the peaking market immediately, (maximum market). This could occur only if the battery systems are presently superior to gas turbines and if there is no risk associated with the new technology (e.g. if there were no questions about the spinning reserve credit). This situation is clearly unrealistic.

6.0 Sensitivity of the Benefits of Battery Storage Systems to Program Alternatives

Using Figures 6 and 7, it is possible to assess the benefits of various program alternatives. For example, present batteries cost \$445/kW and could save roughly .3 Quads of oil per year by the year 2010 (a total of roughly 2 Quads of oil between 1985 and 2010). A program to develop, before 1985, a battery which would cost \$350/kW could lead to savings of approximately .6 Quads of oil per year by 2010 (a total of roughly 5.5 Quads of oil between 1985 and 2010). Greater cost reductions would

* Each MW of battery capacity installed saves approximately 1,600 barrels of oil per year.

yield only marginal (less than 20% in 2010) results until these reductions made it possible for batteries to compete with gas turbines without either the spinning reserve credit or the assumption that fuel costs increase 2.4% per year faster than inflation.

Program alternatives which tend to delay the initiation of the market for a few years but have no other effect on the market, may have a marginal effect on the total energy saved. For example, if no \$350/kW battery systems were installed until 1990, only 3 GW out of the total of 26.5 GW installed by the year 2000 would be affected (a drop of 11% in total installed capacity in 2000). The exception to this would be any delay in the construction of the Demonstration Plant.

The market curves in Figure 5 are do not apply if the Demonstration Plant is not built. A five year delay in the construction of the Demonstration Plant would probably shift the early portion of these curves over by five years with a resulting 40% drop in the benefits that might be obtained in the year 2000 from the use of battery systems. The market (MW installed per year) would probably not return to the undisturbed case until the year 2014 for the batteries which cost \$445/kW (2007 for batteries that cost \$400/kW and 2004 for batteries that cost \$350/kW). This is the point where if one accepts the spinning reserve credit, the battery becomes clearly superior to the gas turbine.

7.0 Estimate of "Appropriate" Level of R&D Expenditures

R&D investments in energy technologies present special problems; even if one ignores all the technological and political risk, relating the pay-off (oil saved in the future) from R&D investments made today, is not straightforward. The advent of high oil prices, massive deficits in the balance of payments, inflation, high interest rates and the complex interrelationships between them makes the calculation of the return from energy R&D (and thus the appropriate level of investment) rather speculative. Since it is not possible to consider all these factors in a study of this size, conventional calculations of the present value of the benefits (using discount rates of 6%, 10% and 20%) that

might accrue before 2015 are the only alternatives. However, since none of the discount rates are without bias, the results should be used only to indicate which program alternatives yield equivalent benefits. (A barrel of oil is assumed to cost \$12.75 in 1977.)

The appropriate discount rate for the government might be the treasury's borrowing rate of roughly 6%. The results of a present value calculation using a 6% inflation rate and a 6% discount rate would be the sum of the value of oil savings in constant dollars. The results of this calculation would give equal weight to all the costs associated with oil saved, no matter when the oil is saved. Because the cost of oil is expected to escalate at 2.4% per year, the calculation tends to ascribe disproportionate importance to barrels of oil saved in later years. The magnitude of the results of these calculations should be viewed with some scepticism.

If one assumes that inflation rates will remain at 6% per year indefinitely, an appropriate discount rate might be 10% per year. This is a high discount rate for the government and a low rate for unregulated industries; it is approximately correct for regulated industries like the electric utilities. Unfortunately, a present value calculation using 10% per year, tends to ascribe a disproportionate importance to benefits that accrue in the near future compared to those that accrue in later years; thus the magnitude of the results of these calculations should be viewed with some scepticism.

A 20% discount rate might be appropriate for an unregulated industry (6% inflation). A present value calculation using this discount rate will clearly ascribe a disproportionate importance to the barrels of oil to be saved in the near future. However, it also tends to limit the planning horizon. In this calculation, a barrel of oil saved in the year 2015 is counted the same as .05 barrels of oil saved in 1985.

If the assumed discount rate were 8.54%, all oil savings, no matter when they occur, would be given equal weight. The results of the present value calculation would be proportional to the values shown in Figure 7.

TABLE 2.1
PRESENT VALUE (1977) OF OIL SAVED BETWEEN THE YEARS 1985 and 2015
(BILLIONS OF DOLLARS)

BATTERY COST	DISCOUNT RATE		
	6%	10%	20%
\$445/kW	19.2	5.58	.346
\$400/kW	29.9	9.16	.683
\$350/kW	43.9	12.55	1.247
Maximum Market	52.8	15.90	1.862

TABLE 2.2
RATIO OF PRESENT VALUES OF OIL SAVINGS USING
DIFFERENT DISCOUNT RATES

BATTERY COST	DISCOUNT RATE		
	6%	10%	20%
\$445/kW	1	1	1
\$400/kW	1.56	1.64	1.97
\$350/kW	2.29	2.25	3.61
Maximum Market	2.75	2.84	5.381

Since it is impossible to know if any oil will be available to be saved in the year 2015, these figures should also be viewed with some scepticism.

Since none of the present value calculations can be accepted as being without bias, they cannot be used directly to measure the benefits that might accrue from R&D expenditures. However, the ratios (relatively insensitive to the discount rate) of the present values for various program alternatives might be a proper guide to the appropriate relative R&D funding levels; these ratios make it possible to compare the relative benefits of different programs.

The "benefits" associated with the battery systems (Tables 2.1 and 3.1) are quite large and, by themselves can give no guidance as to the level of R&D expenditure that might be justified by these benefits. On one extreme, if no R&D funds were expended, there would be no benefits; however, there is no guarantee that a maximum level of R&D expenditures could bring these benefits within reach. One can only consider the relative benefits of alternative programs along with independent technical assessments of the probability of the successful completion of the alternative programs. The absolute magnitude of the various R&D expenditures must likewise be determined by comparing the costs, benefits and probability of success of all the various alternatives.

The present value(s) of the oil saved if the market develops in the manner shown in Figure 5 are shown in Table 2.1 for the various discount rates. These values have been "normalized" by dividing each entry by the appropriate present value for the battery system which costs \$445/kW (present day technology); these ratios are presented in Table 2.2. The entries in this table for the 6% and 10% discount rates are remarkably similar to each other and differ from entries for the 20% rate. The reason for the difference is that the 20% discount rate gives a tremendous credit to early benefits. The lower the capital cost, the faster the batteries will enter the market and early market entry yields a large increase in the present value.

TABLE 3.1
PRESENT VALUE (1977) OF OIL SAVED BETWEEN THE YEARS 1990 and 2015
(ALL BATTERY SYSTEM PURCHASES DELAYED FIVE YEARS)
(BILLIONS OF DOLLARS)

<u>BATTERY SYSTEM COST</u>	<u>DISCOUNT RATE</u>		
	6%	10%	20%
\$445/kW	8.65	2.41	.131
\$400/kW	16.5	4.83	.309
\$350/kW	27.3	6.93	.620
Maximum Market	35.5	9.66	.980

TABLE 3.2
RATIO OF PRESENT VALUES OF OIL SAVINGS USING
DIFFERENT DISCOUNT RATES
(ASSUMING SYSTEMS IN TABLE 2.1 ARE DELAYED FIVE YEARS)

<u>BATTERY SYSTEM COST</u>	<u>DISCOUNT RATE</u>		
	6%	10%	20%
\$445/kW	.451	.432	.379
\$400/kW	.859	.866	.893
\$350/kW	1.422	1.242	1.792
Maximum Market	1.849	1.731	2.83

If the whole program is deferred for five years, the present values for the resulting 25 year program are reduced significantly. These modified values are shown in Table 3.1. Table 3.2 indicates that roughly the same benefits would accrue if either commercialization began in 1985 with present day systems or if commercialization was deferred for five years until a \$385/kW battery system were available. If the program were deferred five years and R&D made it possible to reduce the system costs to \$350/kW before beginning commercialization the benefits would be from 24 to 79% greater than beginning in 1985 with present day technology.

The use of new batteries would increase the utilities' perceived risk; if the market is not to be deferred several years by this perception, this risk must be reduced. The only available methods of reducing the perceived risk are the use of the B.E.S.T. facility to test the battery and the operation of the Demonstration Plant for the intervening five years.

While it is not possible to define exactly those RD&D expenditures which might be justified by the present value of the benefits of RD&D, some general rules of thumb may be applied. An RD&D program can be broken down into the following three parts (in commercial terms):

- Applied Research,
- Development, and
- Design Development
(leading to the delivery of a product).

In "high technology" commercial organizations, the present values of RD&D funds are frequently split between these three phases in the following way:

- One part in 13 for Advanced Research,
- Three parts in 13 for Development, and
- Nine parts in 13 for Design Development.

The total present value of the expenditures should roughly equal one third of the expected benefits.*

If one assumes that the seven years between now and 1985 is split so that the first three years is spent on Development, and the last four years is spent on Design Development, it is possible to use the general rules of thumb to estimate the justifiable level of RD&D expenditures for this market. The rules do not apply if the series of present values does not converge; this will be the case when the discount rate is less than 13%. Thus, the only values in Table 2.1 for which this applies are for the 20% discount rate.

Manipulating the entries (see Appendix B) in Table 2.1 in the manner described yields the values indicated in Table 4.

TABLE 4
"JUSTIFIABLE" YEARLY RD&D EXPENDITURES FOR LOAD LEVELING
BATTERIES (MILLIONS OF DOLLARS -
20% DISCOUNT RATE)

<u>Battery Cost</u>	<u>Development</u> (per year for 3 years)	<u>Design Development</u> (per year for 4 years)
\$445/kW	11.4	48.1
\$400/kW	22.5	94.9
\$350/kW	41.2	173.0

* In this case, the benefits would be the present value of the oil saved by the use of Battery Storage Systems.

If Battery Commercialization were to be deferred for five years, the present value of the "justifiable" RD&D expenditures would be reduced, but the initial yearly expenditures would not be significantly changed. If one assumes that the twelve years between now and 1990 is split so that the first five years is spent on Development and the last seven years is spent on Design Development, manipulating the entries in Table 3.1 yields the values indicated in Table 5.

TABLE 5
 "JUSTIFIABLE" YEARLY RD&D EXPENDITURES FOR LOAD LEVELING
 BATTERIES (MILLIONS OF DOLLARS -
 20% DISCOUNT RATE)

<u>Battery Cost</u>	<u>Development</u> (per year for 5 years)	<u>Design Development</u> (per year for 7 years)
\$445/kW	8.8	54.5
\$400/kW	20.7	128.4
\$350/kW	41.6	257.7

REFERENCES

- 1.) MITRE Corporation, "Lead Acid Battery Market Assessment and Commercialization Strategy Evaluation". October, 1977.
- 2.) Arthur D. Little, Inc., "Commercialization Strategy for Lead/Acid Battery Systems in Load Leveling Applications", Report in Preparation.
- 3.) Public Service Electric and Gas Company, "An Assessment of Energy Storage Systems Suitable for Use by Electric Utilities", EPRI EM-264, ERDA E(11-1)-2501, July 1976.
- 4.) Public Service Electric and Gas Company, "Economic Assessment of the Utilization of Lead-Acid Batteries on Electric Utility Systems", November, 1977.

APPENDIX A
TECHNIQUES USED TO EXTRAPOLATE MITRE'S
MARKET PENETRATION CURVES

It was assumed that MITRE's market curves (Figure 2) were the lower ends of standard market penetrations (such as that shown in Figure 1) where the maximum market size increased 4% per year, i.e. maximum market = $M(1985)(1.04)^{y-1985}$. The curve in Figure 1 was assumed to vary with relative values of battery systems and gas turbines in the following way:

$$\begin{aligned} \text{fraction of market} &= 2c^2 & 0 \leq c \leq \frac{1}{2} \\ &= \frac{1}{2} + 2\left(c - \frac{1}{2}\right)^2 & \frac{1}{2} \leq c \leq 1 \end{aligned}$$

where c = a measure of the relative values of the two technologies.

MITRE assumed that the only applicable measure of relative values was the tradeoff between increased fixed costs and decreases in operating costs; of the latter, the most important were the costs associated with fuel savings. Using the costs for Case B in Table 1, the overall increase in fixed costs would be \$270/kW (445 - 55 - 2 - 118) and the decrease in operating costs would be \$214/kW. If the operating savings equaled the increase in fixed costs, on the average the technologies would be equal and each would capture half the market ($c = \frac{1}{2}$). Thus, it would be reasonable to expect c to have the following dependence on the year:

$$c = \frac{1}{2} + a \left(270 - 214(1.024)^{y-1985} \right)$$

where a is some positive proportionality factor.

Combining this expression with the expression for the maximum yearly market for peaking equipment yields the following expression for the yearly market (MW/yr) for batteries as a function of the year for $c < \frac{1}{2}$.

$$m(y) = 2 \times M(1985)(1.04)^{y-1985} \left(\frac{1}{2} - a \left[270 - 214(1.024)^{y-1985} \right] \right)^2$$

Using this expression, and the appropriate values from the curves of Figure 2, one can obtain approximate values for $M(1985)$ and a .

One can use the expression derived above to extrapolate MITRE's curves to later years ($y - 1985 > 10$) and to markets for battery systems having significantly lower costs. Extrapolating the results to later years is relatively straightforward; however, care must be taken to note when c begins to exceed $\frac{1}{2}$ and change the functional dependence of $m(y)$ accordingly. The market for batteries costing less than \$445/kW can be estimated by subtracting the cost reduction from the value \$270/kW contained in the expression for c .

APPENDIX B

SAMPLE CALCULATION OF RD&D EXPENDITURE PATTERN

If one assumes that all batteries are out of the research phase and into the development and design development stages, the present value of the development costs will equal one third of the present values of the design development costs. It can also be assumed that if the product is to be brought to the market in 1985, of the intervening seven years, three years will be spent on the design phase and four years will be spent on design development. These assumptions, expressed in mathematical terms, imply the following:

$$\bullet \quad x + \frac{x}{1.2} + \frac{x}{(1.2)^2} = \frac{1}{3} \left(\frac{y}{(1.2)^4} + \frac{y}{(1.2)^4} + \frac{y}{(1.2)^5} + \frac{y}{(1.2)^6} \right)$$

where

x = the expenditures per year (in current year dollars)
for design,

y = the expenditures per year (in current year dollars)
for design development, and

.2 = the discount rate.

$$\bullet \quad x + \frac{x}{1.2} + \frac{x}{(1.2)^2} + \frac{y}{(1.2)^3} + \frac{y}{(1.2)^4} + \frac{y}{(1.2)^5} + \frac{y}{(1.2)^6} = \frac{\text{PV of Savings}}{3}$$

where the present value of the savings is taken from Tables 2.1 and 3.1.

The entry in Table 2.1 for a \$445/kW battery system, 20% discount rate, is 346 billion dollars; substituting this value into the two equations and solving for x and y yields x = 11.4 million dollars per year and y = 48.1 million dollars per year. x and y are not assumed to increase each year in response to inflation; this assumption is a contradiction of

the assumption of a 20% discount rate. However, since the technique can only yield gross approximations to the "justifiable" levels of RD&D expenditures, the results are still reasonable. No inflation rate was assumed because it was not clear how the discount rates and inflation rates would be related at these levels, i.e., at a 20% discount rate.